Progress on Development of an Intrinsic Earth Surface Material Classifier

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ABSTRACT: Sensor developers require the capability to quickly and easily generate scenes used to test sensor designs. As with the model atmospheres used by radiative transfer programs, the sensor design community recognized the need for model terrain materials with full optical, thermal, and microwave specifications. Funding has been identified at the Office of Naval Research within their SBIR Program to begin the review, design, and testing of various aspects of just such a standards database, hereafter referred to as the SISO Intrinsic Earth Surface Materials Classifier System. The basic concept of this program is two-fold in that the system design will provide: First, best estimates of a spectral image's pixel identity based on the derived intrinsic physical properties of the pixel (indexed to a standards catalog); and second, simulated spectral information for a pixel under any user specified sensor and environmental conditions. The spectral wavelength region under consideration for the system extends from the visible through the microwave radiation region. The objectives for this Phase I project are: (1) to identify the models and data sets to be used in the standards development;- (2) to provide a software and operations development plan for optimizing the selection of standards;- (3) to provide a software development plan for software modules to facilitate the implementation of the standard in executing code;- and (4) to provide a strawman candidate

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for the Classification Standards, which includes surface materials, cross indices to existing material codes, properties and radiometric models, and quantitative measures of accuracy and importance. This paper provides a general (brief) outline of the complete system and, it is our hope, a starting point for our discussions and interactions with various agencies and groups that have interest in such a system.

1. BACKGROUND

Remote sensing technologies have produced a vast amount of spectral data [1] which records the radiant energy from various earth locations at different wavelengths. Such data sets are dependent upon the sensor characteristics (e.g. spectral and spatial resolution, projection), viewing conditions, and the environmental conditions under which the measurements were taken. The dependency of spectral data sets on various measurement parameters makes it difficult to integrate information from different sensors acquired at different times or make sensor response predictions for new situations. As the result of this limitation, new measurements and data sets are often desired for analyses in each new application.

To facilitate the development of a universally applicable dataset, we are developing software to support the reduction of spectral data measurements into intrinsic earth-surface material descriptors. In addition, it will be possible to reconstruct such image data sets from intrinsic descriptors. Such descriptors consist of the objective characteristics of a particular material rather than the way it appears to a specific sensor under specific illumination or viewing conditions.

Initial requirements for the development of Earth Surface Intrinsic Material Descriptor Standards have been promoted by participants in the SISO SNE and SENS Fora who are interested in providing content standards to populate the SEDRIS [2] data structures and promote interoperability within HLA [3] federations. A review of the intrinsic surface classifications in the DFAD standard [4] showed this to be inadequate for the reconstruction of accurate sensor views. This inadequacy was further accentuated with the requirements for IR and optical sensor perspective view generators being developed to operate at the 1 meter or less spatial resolution [5]. The need for intrinsic material descriptor-code standards to operate across the visible to the radar spectrum in order to support realistic tactical battlefield sensor simulations has become more urgent as such systems mature to operational status [6]. The first step toward such standards was taken with the development of an IR data dictionary [7,8] intended to establish the exact definitions and formats of parameters required for IR scene reconstruction. This data dictionary has been proposed for consideration as a SISO standard and is proceeding through the standards review process.

In the meantime initial funds have been procured from the Office of Naval Research [23] and are being managed by the Naval Postgraduate School in Monterey for the development of intrinsic earth surface standards. If successful, this effort will lead to a Phase II development program designed to build software and demonstrate the spectral data classification process.

This paper describes the progress made in the development of *the* intrinsic surface material standards project and invites members of the SISO community to participate in its further development.

2. OBJECTIVE

The objective of the intrinsic earth-surface material-code development project is to develop a standard mechanism to encode remotely sensed, earth-surface radiances collected under one set of measurement conditions into a Standard Surface Material Code (SSMC; Encoder Module) and be able to calculate the expected surface radiances under a different set of measurement conditions (Decoder Module). Figure 1 shows a block diagram of the process.

The measurement conditions shown in Figure 1 include:

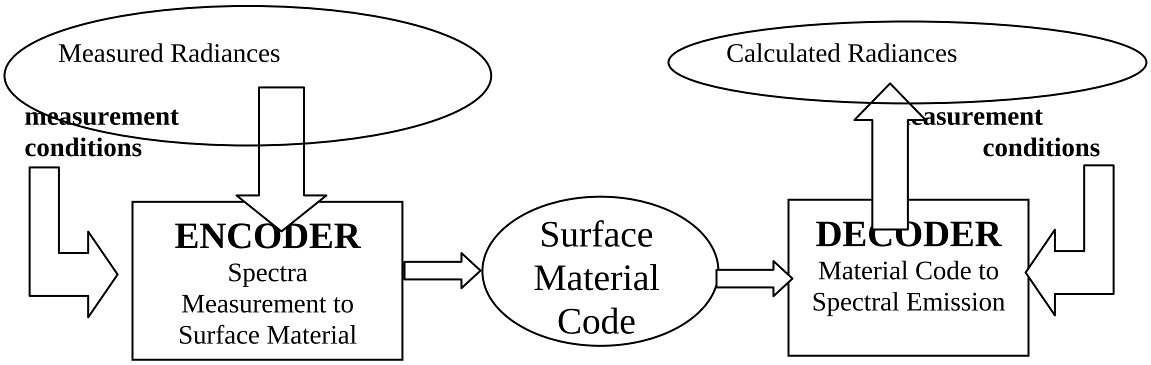

Figure 1 - Intrinsic Earth Surface Material Encoding Process

1. Environmental conditions such as illumination, atmospheric attenuation, temperature, wind speed and direction, humidity, and the like;
2. Sensor model such as camera parameters and lens distortions;
3. Ephemeral surface conditions such as moisture and dust coverings; and
4. Seasonal and diurnal effects such as vegetation growth histories.

In short, all factors need to be considered that can be ascribed to the conditions under which a spectral measurement is taken and that must be specified in order to calculate the response of a sensor viewing the surface under a different set of circumstances constitute the measurement conditions.

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3. SSMO Open Standard Format

The intrinsic earth surface material code development project consists of an open standards component funded and directed by government resources and a software development component seeded by government funds [8]. The commercial development effort is expected to result in functioning Encoder and Decoder software products, and for which funding is expected to be provided by industry.

The open standards component can be conceived envisioned as a table of the form shown in Figure 2.

Figure 2 Standard Surface Material Code Table

Properties / Surface Material		Physical Properties						Auxiliary		
		Vis Model		IR Model		Radar Model		Importance	Accuracy	Synonym
Code	**Description**	**Para-meters**	**Form-ula**	**Para-meters**	**Form-ula**	**Para-meters**	**Form-ula**			
0	black body									
1										
...										
n	typical surface									
...										
255	transparent									

The components of this table are described as follows:

Code - The standard surface reference number assigned to a patch of earth, building, or visible feature. It will be used as a pointer in runtime software to branch to the location at which the rest of the information required for surface rendering calculations is found and are performed. The values shown in figure 2 are from 0 to 255. This number of codes represents an initial goal for the project. It is expected that code assignments will follow scalable material taxonomies so that expansion of the table to a larger number, and presumably more accurate codes, is possible.

Description- This is a short colloquial description of the material. This should be suggestive of the surface type and aid understanding and usage of the codes. Names such as slate, asphalt, sand, and water would be examples. It is important to emphasize that the standard code refers to intrinsic radiometric characteristics. We are not defining a "slate" and are not intending to measure exact characteristics of a slate. We are defining a standard radiometric behavior with a code. An alternate name for the code might be "rock" and any material that has similar radiometric behavior would be classified under the same code.

Physical Properties - Under this broad category are the references to radiometric models and formulae used to calculate the radiant energy from a surface under specified conditions. The parameters under this heading refer to the both the intrinsic surface properties and the environmental conditions under which they are observed. Multiple model/parameter categories are shown since it is assumed no one model will cover all wavelengths and hence multiple references will be required. Three divisions are shown in Table 2. These are reflectance, thermal, or microwave wavelength regions. These are not fixed, but could be expanded or contracted depending upon the accuracy.

Reflectance Model - Model and parameters used to calculate the surface radiometric response in the visible through shortwave IR wavelength region.

Parameters - The column contains intrinsic values (e.g. reflectivity, absorptivity, surface roughness) used to define the surface material.

Model – Radiative Transfer code(s) which performs the radiometric surface calculation. The model consists of (1) formulae that specify the mathematical calculation and (2) variable parameters used to define the environment, illumination, and viewing conditions, or seasonal variations required for the calculation. Examples would be sun angle, cloud cover, view angle, and time of year.

Thermal Model - Same as Reflectance Model entries except applicable to the thermal infrared region. Parameters and model formula will emphasize thermal loads, temperature, etc.

Radar Model - Same as Reflectance Model entries except applicable to the millimeter to centimeter and meter wave regions. Parameters and model formula will emphasize EM response to dielectric and surface-roughness properties.

Auxiliary - Additional information not specifically required for radiometric calculations but useful for understanding or executing the standard. Only three categories are shown in Figure 2. Many more could be added.

Importance - This parameter is an indicator of the importance of the category. Since we are building an earth surface, the first cut at the definition of this parameter is simply the material abundance or fraction of the earth surface covered by material corresponding to the code category. We expect further refinements of this parameter to include some measure of value represented by the surface covering. It is highly likely that arctic ice will not be as important as road surfaces in urban environments; hence, a simple square meter ratio is not the best measure, and a better measure is expected to be developed for the standard.

Accuracy - The accuracy parameter specifies the radiometric accuracy with which a surface signature can be calculated from the models and parameters specified for this code category across the wavelength regions. Although a single summary parameter is indicated this value is expected to represent the average or summary of accuracy parameters applicable to the individual

modules. The choice of surface material categories will be a trade-off between Accuracy and Importance. Higher accuracy is achieved by narrowing the applicability of the code category and thus reducing its importance.

Synonyms - This table entry is to allow additional parameters to be added to define real materials included in the specified code category. Of specific interest are cross-reference tables to existing surface categories. References to the old DFAD product and to some extent applicable categories of the FACC feature classification schemes could be very useful additions which belong in the Synonym category.

3.1 Accuracy Criteria

Accurate radiometric calculations from intrinsic surface material properties are notoriously difficult [9,10] and subject to large errors due to impurities and small variations in measurement conditions. The traditional measurement of accurate spectra comprises a large body of recorded literature in chemical domain [11] and is typically the objective of spectral signature investigations for remote sensing platforms [12]. Given the current state of the art it would be hopeless to approach an intrinsic earth surface standard definition project with the accuracy philosophy driving the work in the chemical or spectral remote sensing domains. Instead this project will take a pragmatic approach to the accuracy question by allowing this criteria to float.

Our position is that at present no consistent standard exists by which computer simulations, reconnaissance analysis, and weapon-detection sensors can share sensor signature data that requires the translation from one to another view environment. Hence any progress along these lines is a step in the right direction. Furthermore, calculated views are typically presented on CRT screens, photographic film or printed media all of which are subject to distortions (e.g. brightness, contrast) that are quite acceptable to human operators for many applications because human perception can adjust to relative brightness changes. Consequently we do not require a high degree of accuracy in the reproduction of spectral signatures of actual materials found in nature but rather apply the following two criteria:

1) Consistency in calculations
2) 80% criteria for real surfaces.

"Consistency in calculation" means that one user of the standard can be sure that if the user calculates the emitted energy from a specific surface code under certain conditions that a second user will also calculate the same emitted energy. It therefore suffices for the first user to send only the code itself when communicating with a second user of the standard. If the second user chooses a set of view conditions convenient to their perspective (e.g. different view angle, different time of day) and calculates the "look" of the surface from this viewpoint, *then* both users can be confident that they are looking at the same surface.

In this sense our standard project proposes to replace the world with a set of (initially 256) artificial surfaces defined only by the formulas and parameters used to calculate their radiometric behavior. A SISO Rock therefore does not represent any one rock in Nature but is rather an agreed upon entity used only for consistent communication between participating users. This concept is similar to the definition of a Standard Atmosphere used in Meteorology to define a large set of atmospheric conditions that are only approximated by the real atmosphere on any one day.

The second or 80% criteria address the relationship between the SISO Surface Material categories and real earth surfaces. This represents a statement addressing the accuracy with which a specific code category actually represents the behavior of any real material included in the code class encountered in Nature. To exemplify this concept consider Figure 3. Assume the solid line represents the spectral response of a typical SISO code category. Assume further that the dashed line represents the actual spectra of a real material measured under the same conditions as the calculation. The shaded area then represents the difference between the two curves.

If we assume the emissivity is represented as a gray shade between 0 and 256 values on a CRT display the integrated error could average to 51 levels and meet the 80% accuracy criteria. If the same comparison were done over a set of calculation conditions (e.g. temperature, view

angle) and the errors averaged a similar number could be developed to categorize the accuracy of the spectral behavior of the real material vs. the standard material.

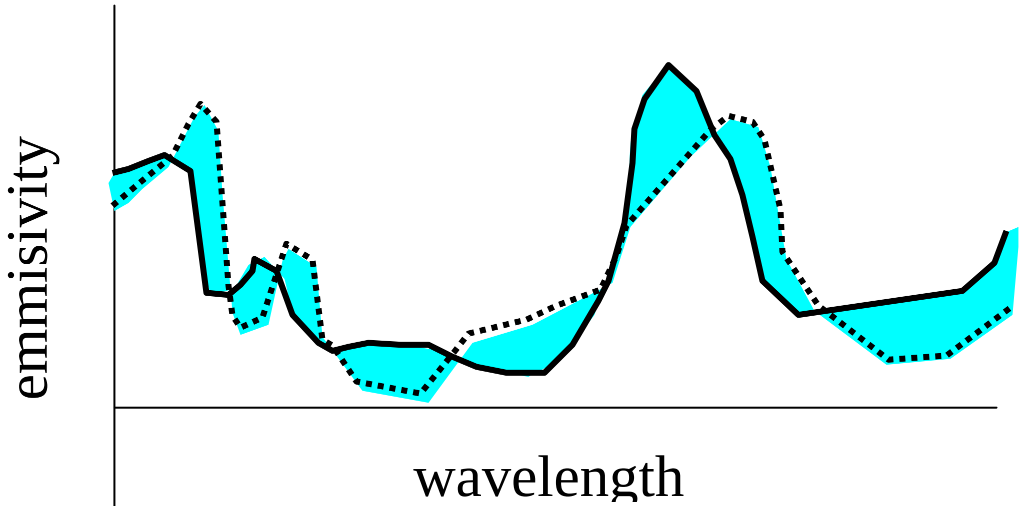


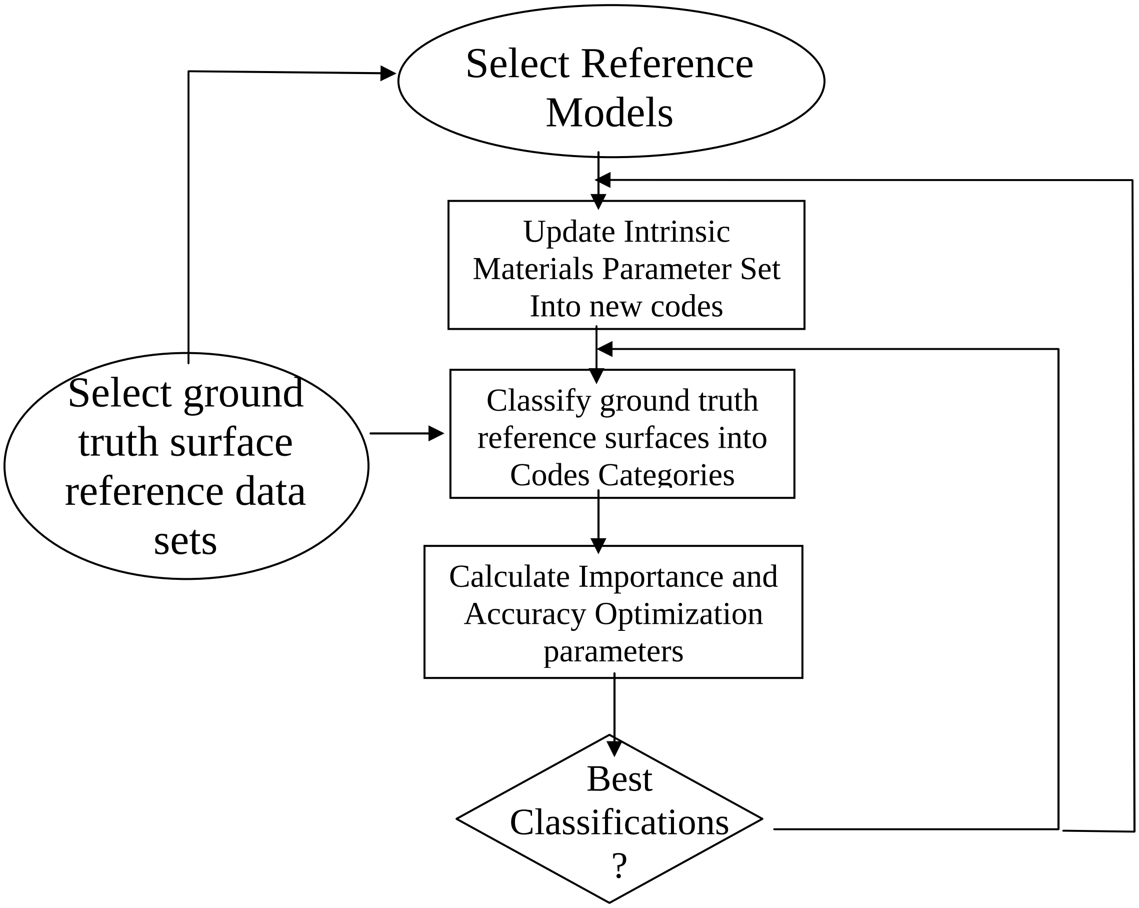
Figure 3 - Pictoral Representation of 80% Accuracy Criteria

We have used 80% as a convenient way of labeling this idea. In actuality the accuracy number shown in the Auxiliary Data category of Figure 2 is meant here. It will generally vary with the number of materials included in the category. By definition the value is 100% if the abstract SISO material code represents exactly one type of surface occurring in nature. In this case however the Importance number assigned to the code would approach zero since it is unlikely that a material corresponding exactly to any model calculation exists anywhere in Nature. On the other extreme if we chose to include all materials found on the earth in a single category the average gray shade error would approach a random noise correlation. This category would be very important since the whole earth is included but its accuracy approaches zero.

The ideal code category set would maximize the sum of the products of the Importance and Accuracy values over all 256 codes and at the same time have each Importance value be approximately equal.

4. Standards Optimization Process

As described above the selection of surface material standards is essentially a large optimization problem. The optimization attempts to find both the best spanning set of radiometric behaviors and the best division of earth surface materials into the behavior set. Figure 4 shows the basic flow diagram describing such an optimization problem. First a set of models (formula and variables) must be defined which are capable of calculating radiometric signatures under a variety of environmental and measurement conditions. Second a set of measurement databases must be found which act as ground truth for the optimization. This set of measurement databases will provide (NREF) reference sets of measurement conditions under which the measurements were acquired.



The optimization then proceeds by selecting a set of 256 intrinsic characteristic parameters. Each set describes one code as defined in the first column of Figure 2. The models are then run to generate a set of 256 x NREF set of calculated spectral curves. The calculated spectral curves are then used to generate Importance and Accuracy values for each code/category combination. For each combination the Importance times Accuracy sum is generated to act as the optimization criteria. Two optimization loops include re-categorizing measured surfaces into alternative code categories and selecting new code categories by varying the intrinsic materials that define the standard codes.

The result of this optimization will produce:

1. A set of standard models used for radiometric calculations;
2. A set of 256 intrinsic material definition parameters;
3. A set of pseudonyms for materials classified into these categories; and
4. A set of Importance and Accuracy values quantifying the quality of this standard relative to the ground truth data sets selected.

4.1 Model Candidates

The sensor systems that detect radiation from the surface differ between the passive sensors that detect visible through long-wave infrared radiation and the generally active sensors that both send and receive microwave radiation. The radiometric models that relate digital numbers recorded by a sensor to actual surface properties are also different.

The atmospheric components need to be estimated for the particular atmospheric conditions of the data acquisition using atmospheric models, such as 6S [13] or MODTRAN4 [14]. Reflectivity and emissivity are unitless ratios that describe the proportion of

energy either reflected or emitted for a given solar radiance or blackbody radiance (at a particular temperature), respectively. Surface roughness at regional and subpixel scales effects surface radiance at all wavelengths and may need to be considered in the models. The long-wave radiance model is also effected by particular intrinsic properties (such as specific heat, conductivity, density, and thickness of the surface material), but is also influenced by environmental (weather) conditions (such as cloud cover, humidity, precipitation, wind) that effects solar loading, convective, radiative, and evaporative cooling, and transpiration.

For the microwave wavelength region there are two parameters, in a general sense, that are of particular interest for the identification of surface materials:

(1) complex dielectric constant and,
(2) surface roughness.

Over the last two decades theoretical and empirical research has led to well established models for dielectric characteristics of many natural and artificial pure and mixed materials. These material curves generally show relative permeativity (dielectricity) as a function of radar frequency, polarization and incidence angle. Hence, in the framework of the proposed project, part of the effort will be spent on the standardized compilation of existing material dielectric characteristics versus observing and environmental parameters.

Surface roughness plays a key role for microwave backscatter. Numerous models and empirical measurements exist which link radar backscatter with the surface roughness attributes (rms height and roughness correlation length). Generally, roughness from a radar perspective scales with observing frequency. An increase in wavelength (decrease in frequency) decreases the sensitivity to small scale roughness changes (e.g., soil surface roughness) while larger objects determine the radar backscatter variations. Hence, it is critical to incorporate adequate models into the standard catalogue of surface materials which allow the computation of radar signatures based on wavelength.

The challenge of radar analysis, as it is in the other wavelength regions, is the deconvolution of the signal into meaningful biogeophysical parameters. To aid this ongoing research effort, radar backscatter models have been developed over the past two decades. For artificial point targets and simple surfaces (e.g., pavements, water, metal surfaces) models have been developed which allow fairly accurate model inversion. For more complex, multi-layered surfaces and volumes (e.g., bare soil at various roughness stages, snow/ice-cover, agricultural and forested targets) research has provided many approaches to fairly accurately model radar backscatter, given a set of sensor and environmental conditions. Due to the complexity of the scattering process these models are not easily inverted to estimate accurately the biogeophysical characteristics from measured radar backscatter coefficients [15]. However, some success in model-inversion has been achieved with the development of semi-empirical models for multi-frequency and multi-polarimetric data [16].

4.2 Ground Truth Data Sets Candidates

A number of spectral databases currently exist from which to populate the ground-truth data set shown in Figure 4. These data sets will be queried to determine accuracy, measurement conditions, and spectra for the surface materials contained in our intrinsic classifier. The following is a preliminary list of these sources:

- Army Corps of Engineers' Topographic Engineering Center at Fort Belvoir [17]
- Georgia Tech
- Infrared Information Analysis Center at the Environmental Research Institute of Michigan
- Jet Propulsion Laboratory [18]
- Johns Hopkins University [19]
- NEF [20]
- Purdue University [21]
- Radiation Laboratory at University of Michigan
- RELAB (Brown University)
- Technology Service Corporation
- U.S.D.A. Remote Sensing Research Center
- U.S. Geological Survey [22]

5. Progress Report

At the time of writing the development of Intrinsic Earth Surface Material code standards has progressed to the point that Phase I contracts have been let to several companies represented by some of the authors. These events have just happened so no time has elapsed for publication of the results of this effort. Progress will be reported in verbal presentations if this topic is selected at the Fall 1990 SISO conference.
The objectives for Phase I are:

1. To provide an identification of the models and data sets used in the standards development;
2. To provide a software and operations development plan for the execution of the standard development optimization problem;
3. To provide a software development plan for the development of Encoder and Decoder modules to facilitate the implementation of the standard in executing code and;
4. To provide strawman candidate first cut of the Standards (i.e. filled out tables from Figure 2).

A non-optimized first cut standards will be presented at the Spring 2000 SISO meeting for review and comment to the appropriate forum.
The Encoder and Decoder software modules will remain the proprietary property of the companies performing the development and are expected to be made available to the simulation and remote sensing communities either as a stand alone system or imbedded product.

6. Conclusion

Intrinsic earth surface material codes are required for the purpose of reducing vast quantities of spectral measurement information to objective "what is on the ground" information. The reduction of measurement to objective descriptions using a consistent and reproducible standard will provide both a mechanism for data reduction, communication between simulators, and a means for sensor signature prediction. Past efforts outlined in this paper toward the development of such standards have now led to a funded effort which is now progressing and will lead to the submission of intrinsic-material earth-surface code standard to the SISO organization.

At present we are soliciting comments, collecting ground-truth data sources, radiometric models, and inviting participation from all interested parties of the SISO organization.

REFERENCES

[1] Rencz, A.N., Remote Sensing for the Earth Sciences; *Manual of Remote Sensing, 3rd edition*, John Wiley & Sons, 1999.

[2] Horan, B. and Cox, R., "Sedris Past, Pesent, and Future - Technically Speaking", In *Proceedings of the Spring simulation Interoperability Workshop,* March 1999, 99S-SIW-057

[3] Jon T. Miller, Reduced Layer Implementation. A Framework for Implementing the High Level Architecture, *Proceedings of the 14'th DIS Workshop, Vol 1* March 11-15, 1996 , p 59

[4] Bill Cornette, Dave Anding, F. Mertz, Land Data Base Requirements for Environmental Effects Models for use in DIS, *Proceedings of the 12' DIS WorkShop*, Orlando, Fl. 13-17 March '95, Position Paper 95-12-019

[5] W. Baer, Global Terrain Database Design for Realistic Imaging Sensor Simulation, *Proceedings of the 13'th DIS Workshop,*Vol I, Sep 18-22'95 Orlando, FL., p 19

[6] W. Baer Real Time Scientific Rendering for General Sensors, *Proceedings of the Spring simulation Interoperability Workshop*, Vol I, p 535 IST-CF-97-01.2 March 3, 1997, IST, 3280 Progress Dr.,Orlando,Fl

[7] Russ Moulton, Max Lorenzo, Bill Cornette, W.Baer, Toward Standards for Interoperability, *Proceedings of the Spring simulation Interoperability Workshop*, Vol II, p 983 IST-CF-97-043 Sep. 8-12, 1997 IST, 3280 Progress Dr., Orlando,Fl

[8] W.M. Cornette, Modeling and Simulation Scene Generation Attributes Standard (Preliminary Draft). NIMA Internal Working Document. Jan 1997.

[9] A. R. Gillespie, S. Rokugawa, S. J. Hook, T. Matsunaga, and A, B. Kahle, Temperature/emissivity separation algorithm theoretical basis document, Version 2.3: ASTER Mission Report, Jet Propulsion Laboratory, Pasadena, 1998, 74p.

[10] J. C. Price, How unique are spectral signatures?: Remote Sens. Environ. 49, 1994, p. 181-186.

[11] G. R. Hunt and J. W. Salisbury, 1970, Visible and near-infrared spectra of minerals and rocks: I Silicate minerals, Modern Geology, Vol. 1, p. 283-300.

[12] F. A. Kruse, A. B. Lefkoff and J. B. Dietz, Expert system-based mineral mapping in northern Death Valley, California/Nevada, using the Airborne Visible/Infrared Imaging Spectrometer [AVIRIS], Remote Sensing of Environment, Vol. 44, p. 309-336.

[13] D. Tanre, C. Deroo, P. Duhaut, *et al.*, Simulation of the Satellite Signal in the Solar Spectrum [5S], User's Guide, Laboratoire d'Optique Atmospherique, U.S.T. de Lille, France, 1986.

[14] A. Berk, L. S. Bernstein, G. P. Anderson, P. K. Acharya, D. C. Robertson, J. H. Chetwynd, and S. M. Adler-Golden, MODTRAN cloud and multiple scattering upgrades with application to AVIRIS, Remote Sens. Environ. 65, 1998, p. 367-375.

[15] D. L. Evans, J. Apel, R. Arvidson, R. Bindschadler, R. Carsey, J. Dozier, K. Jezek, E. Kasischke, F. Li, J. Melack, B. Minster, P. Mouginis-Mark, and J. van Zyl, Spaceborne synthetic aperture radar: Current status and future directions, Technical Report NASA 4679, National Research Council, Space Studies Board, 1995.

[16] Y. Oh, K. Sarabandi, and F. T. Ulaby, An empirical model and an inversion technique for radar scattering from bare soil surfaces, IEEE Trans. Geo. Remote Sensing 30, 1992, p. 370--381.

[17] M. B. Satterwhite and J. P. Hneley, Hyperspectral signatures [400-2500 nm] of vegetation, minerals, soils, rocks, and cultural features: Laboratory and field measurements, U.S. Army Corps of Engineers, ETL-0573, Fort Belvoir, 1991.

[18] C. I. Grove, S. J. Hook, and E. D. Paylor, Laboratory reflectance spectra of 160 minerlas, 0.40 to 2.5 micrometers, Jet Propulsion Laboratory JPL 92-2, 1992.

[19] J. W. Salisbury and D. M. D'Aria, Emissivity of terrestrial materials in the 8-14 μm atmospheric window, Remote Sensing of Environment, Vol. 42, 1992, p. 83-106.

[20] SETS, Inc. Spectral catalog, 5 volumes, 1990.

[21] E. R. Stoner, M. F. Baumgardner, L. L. Biehl, and B. F. Robinson, Atlas of soil reflectance properties, Purdue University, Research Bulletin 962, 1980, 75 p.

[22] http://speclab.cr.usgs.gov

[23] http://www.navysbir.brtrc.com

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